Threading Space: Kinetic Sculpture Exploring Spatial Interaction Using Threads In Motion

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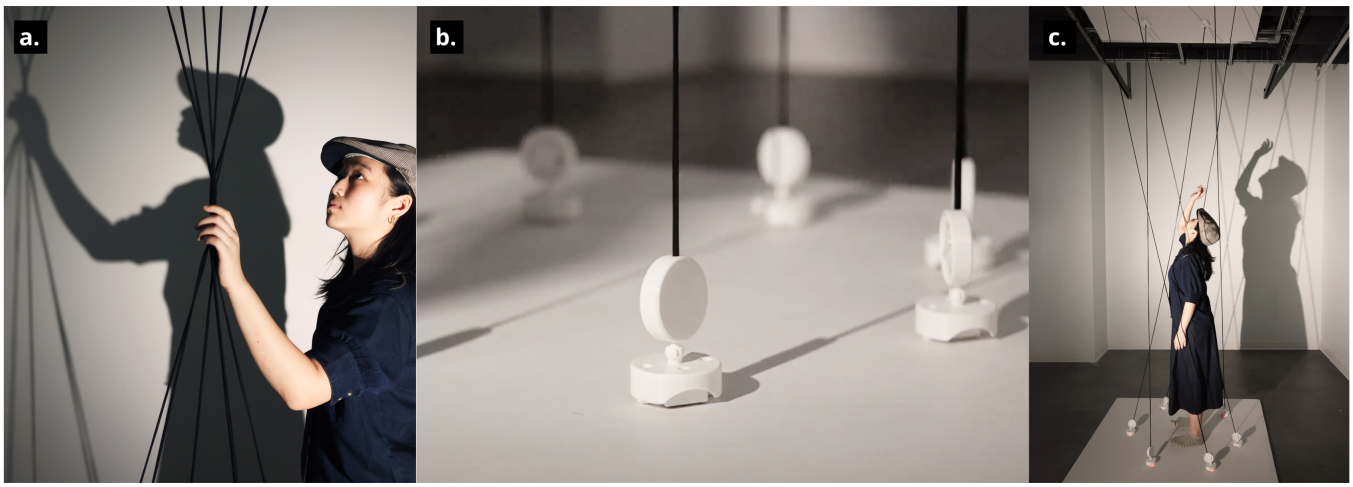

Figure 1: Threading Space (a. Interacting with tangled strings, b. Toio robots in their shells on the floor mat, c. Standing in the middle of a rotating circle of robots as the strings twist)

ABSTRACT

Threading Space is a kinetic sculpture that explores how spatial perception can be transformed by dynamically and geometrically reconfiguring physical lines of thread. As the threads in motion interact, they become a hypnotic medium for three-dimensional patterns. Through a physical installation and an interactive GUI, *Threading Space* invites the audience to explore the potential of using swarm robots and line elements to create, morph, and interact with space.

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CCS CONCEPTS

• **Applied computing** → *Media arts*; • **Human-centered computing** → **Interaction design**; **Interaction devices**.

KEYWORDS

Kinetic Sculpture, Swarm Robots, Thread-based Installation, Actuated Experience

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1 INTRODUCTION

Threading Space is an installation that experiments with manipulating physical space using lines of threads controlled by a swarm of mobile robots deployed on floor and ceiling surfaces. The work outlines planes and volumes in space, creating pseudo boundaries, and plays with the viewer's natural sense of delimitation. We also developed a graphical user interface (GUI) to invite the audience

Figure 2: (Left) The setup of a floor toio robot and (Right) the hardware setup of a ceiling toio.

to participate in this creative process and experiment with the sculpture in real time to change the geometry or dynamism of the moving lines. The robots can adapt to being taken off track, allowing the audience to intervene in their motion tangibly. Incorporating the audience into the system, we aim for this dynamic installation to be a product of a co-created experience. More information showcasing *Threading Space* is available online at: https://www.axlab.cs.uchicago.edu/projects/threading-space.

Employing swarm robots for interaction and expression has been explored in HCI [4, 8] and interactive arts [3] to develop novel embodied experiences, allowing people to interact with collectively moving physical agents. The Actuated Experience Lab (AxLab) at the University of Chicago previously explored deploying magnet-embedded swarm robots on ceiling surfaces to enrich everyday spatial interaction [7, 11]. By manipulating threads dynamically, our work explores novel artistic expression and interaction beyond static line-based sculptures like Fred Sandback's thread-employing vertical constructions [10] or Gego's reticular wire sculptures [5]. Connecting two mobile robots at the ends of each thread and pairing the ceiling and floor robots enables us to program animation sequences and add customizability in "sculpting" this 3D space by dynamically forming various shapes.

2 SETUP AND IMPLEMENTATION

Threading Space connects tailored hardware and a specialized animation system, creating a seamless, 3-dimensional, animated sculpture of threads and robots that provides the viewer with a front-row seat to a dynamic geometric experience.

Hardware: The installation setup consists of two mats that are 1260mm × 1188mm, with one mat on the floor, and a ceiling mat elevated to a height of 2.5m - 3.2m. Ten pairs of toio robots [1] are placed within 3D-printed shells on the floor and the ceiling (Figure 2). Threads (5mm-width stretchy nylon) connect the shells with a passive spring reel mechanism that allows them to collapse and extend as needed to maintain a straight line between the pair. As the robots move around on the ceiling and floor mats, the connected threads can form a wide variety of 3D shapes. The floor and ceiling surfaces are comprised of laminated toio mats, allowing the robots to localize [2], glued to ferromagnetic metal sheets. The work also utilizes a light placed on the floor or ceiling, using the threads as a medium to cast shadows on nearby walls.

Software: *Threading Space*'s animation system that supports two distinct modes of interaction. *Display Mode* cycles through pre-designed animations, each aimed to create a sensation of transforming a user's perception of space. *Interactive Mode* allows users to control and manipulate the animations with fine-grained control with a custom user interface (Figure 5) developed with Processing [9]. They can adapt the speed and other parameters of the floor and ceiling robots through sliders, allowing them to customize the animations.

Threading Space also employs a Multi-Agent Path Finding algorithm [6] to transition between the modes and animations. By traveling on a coordinate plane, the pairs of robots on the floor and ceiling can synchronously and automatically move to prevent collisions of robots and entanglement of threads during the transitions.

3 OFFERED EXPERIENCE / INTERACTION

3.1 Animation Geometry and Viewing Experience

The design of *Threading Space* allows for an infinite variety of animations that can transform space across time. In order to display these possibilities, we pre-designed a series of animations to mesmerize viewers. Our animations are built on two major groups: Circular and Linear Geometries (Figure 3). On top of these geometric bases, we used symmetry and dissonance between the floor and ceiling to form constantly changing shapes and create visual effects.

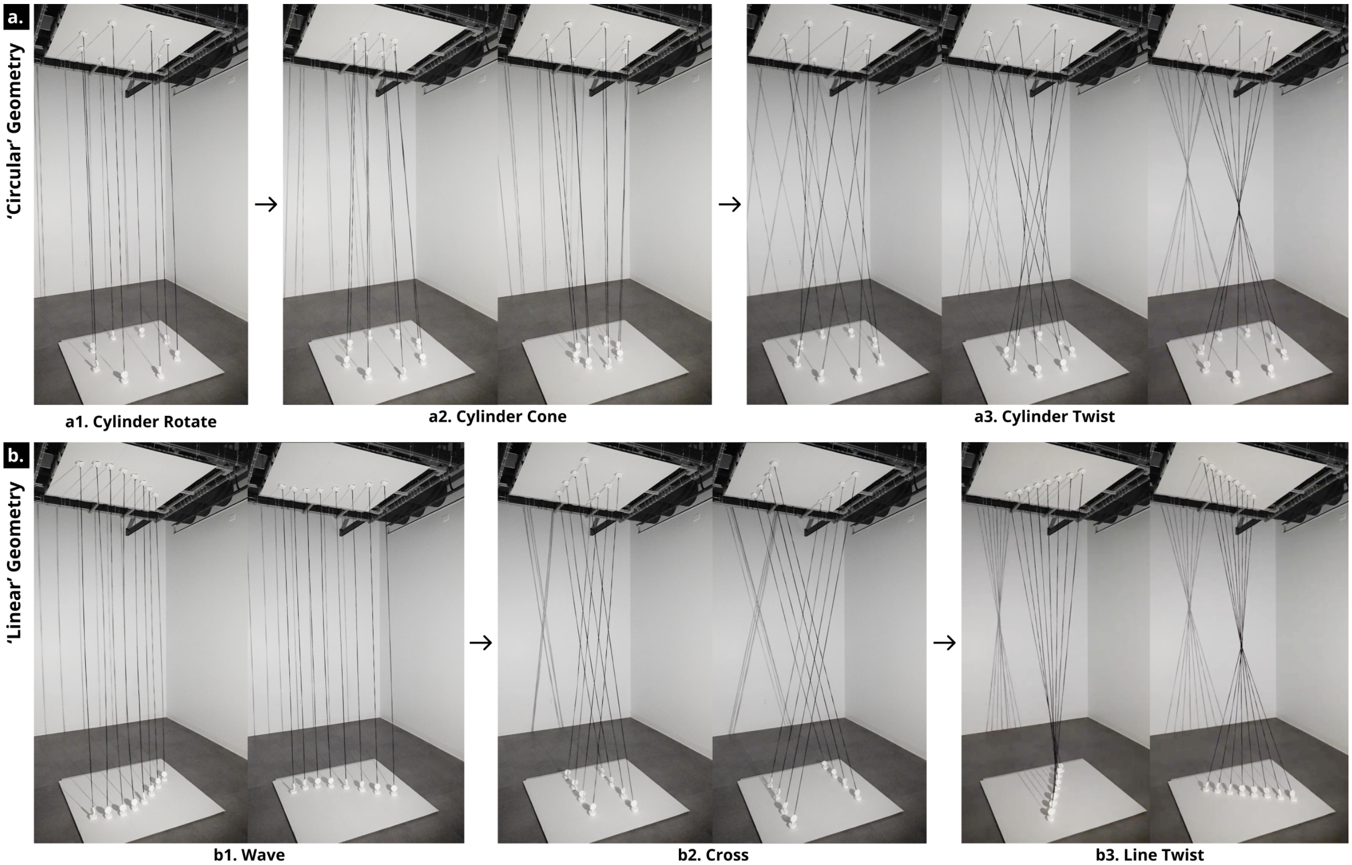

Figure 3: The animations of *Threading Space*, both circular and linear.

Our circular animations transform the rotation and radius of circles on the floor and ceiling to create cylindrical shapes. The base **Cylinder Rotate Animation** (Figure 3-a1) aligns each line of thread to be perfectly vertical, forming the walls of our cylinder. As the robots move, the cylinder rotates at a fixed rate. The **Cylinder Cone Animation** (Figure 3-a2) changes the radius sizes, smoothly oscillating between conical and cylindrical shapes. The **Cylinder Twist Animation** (Figure 3-a3) changes the angular velocities of the robots, causing the threads to twist along a central point, creating a mesmerizing "net" of rotating threads that knot together.

The linear animations form and twist lines between the floor and ceiling to create walls. The **Wave Animation** (Figure 3-b1) uses sinusoidal motion to create wave motion in 3D. The **Cross Animation** (Figure 3-b2) crosses each thread line within the wall, creating a hypnotizing "criss-cross" effect. **Line Twist Animation** rotates the line along a central point (Figure 3-b3).

3.2 Spatial, Tangible and Bodily Interactions

Threading Space allows for a breadth of bodily interactions (Figure 4). Because of the floor-to-ceiling setup, the sculpture takes new forms based on the viewer's position in the room, inviting the viewer to walk around and even through the installation. Users can interact with the sculpture by gently touching and pulling on the threads to affect the overall shape. Due to the ability of each robot to self-correct to animations, viewers can disrupt their motion, allowing for purposeful entanglement and experimentation.

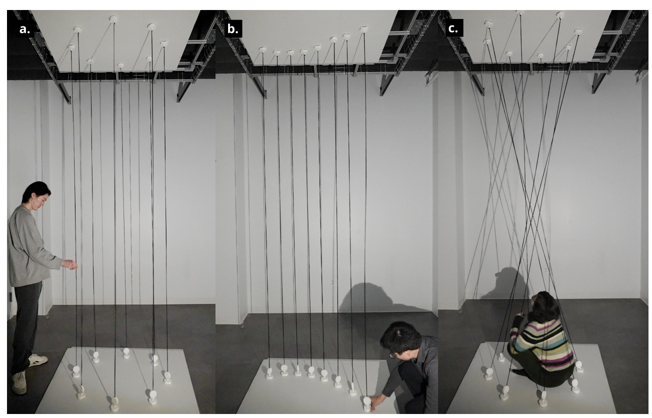

Figure 4: The tangible and embodied interactions of *Threading Space*: playing with threads, moving robots, and viewing the geometry from the inside.

3.3 Controlling the Space (GUI Control)

The interactive GUI allows users to take control of *Threading Space*. By allowing users to control specific parameters of pre-designed animations, they can manipulate 3D space in real-time (Figure 5). The GUI allows the user to configure the speeds of different animations and the shapes of the animations themselves.

Based on our basic geometries, we implemented three different interactive animations. The **Cylinder Mode** builds on the circular animations to control the radius size and the rotation speed of the bottom and top independently, allowing the user to twist and change the angle of the cylinder as they want. Based on our linear geometries, the **Line Mode** allowed users to change the rotating line's speed, enabling the user to move a wall in real space. We also implemented a **Wave Animation**, which allows users to control a 3D wave.

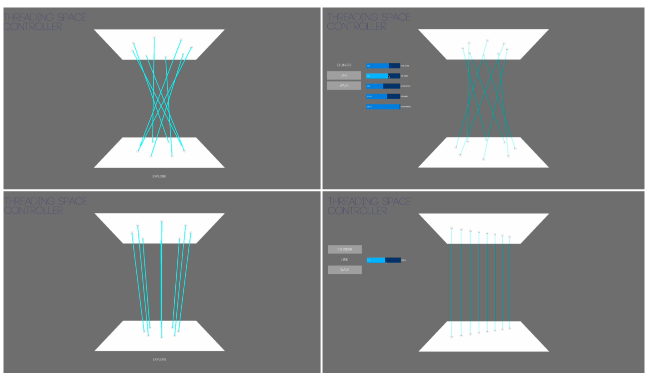

Figure 5: The GUI control tool of *Threading Space*, created in Processing. Each bar represents a different aspect of the animation that can be adjusted by simply clicking and dragging.

4 EXHIBITIONS

Threading Space was previously exhibited at two locations in different capacities. It was first exhibited by AxLab at **Ars Electronica 2023** (September 5 - 10, at Linz Austria), as a room-sized installation (Fig 6-a) [1]. *Threading Space* was next presented at the **Chicago South Side Science Festival** [2] (September 30, at the University of Chicago), this time with a much smaller installation (Figure 6-b). This installation used PVC pipes to create a small structure about 70cm × 94cm × 94cm.

Ars Electronica: The exhibition space at Ars Electronica magnified each aspect of *Threading Space*. Before the audience could even see the sculpture in its entirety, they could hear it; the motors of the swarm robots formed an orchestra of sound corresponding to the morphing space that echoed through the halls. The installation's lights magnified each thread's movement with a shadow on the wall. The multi-sensory experience invited the audience to engage fully in the abstract space of threads, robots, and shadows, immersing themselves in the embodied audio-visual field of the artwork.

The audience's gaze followed the lines of thread as they first saw the moving robots on the floor and ceiling and then perceived the sculpture as a whole. Many audience members stepped back or circled the sculpture to get a more comprehensive perspective, mesmerized by the meditative sound, pattern, and space that transformed seamlessly and dynamically. Others moved closer, following a single line of thread and its shadow, synchronizing their movement with the sculpture.

Each viewer had a unique interpretation of the installation when asked. Some found the construction and reconstruction of space meditative and peaceful, saying that the live sound and the visual effects "seemed infinite" as they immersed themselves in *Threading Space*. Others were fascinated by the twisting and untwisting of the threads, stating that it "weaved a kind of spatial relation between humans and technology." Some even felt the robots were "little spirits that are delightful and radiant, forming a celebratory dance collaboratively." Younger audience members engaged the space with bodily expressions and gently touched the threads and robots, treating them as live beings who could communicate with them.

Chicago South Side Science Festival: In the science festival, both due to the smaller size of the system setup and also because of the science exhibit's atmosphere, children had much more active, tangible interactions and engagements with our work, grasping and moving the robots around, and touching the threads.

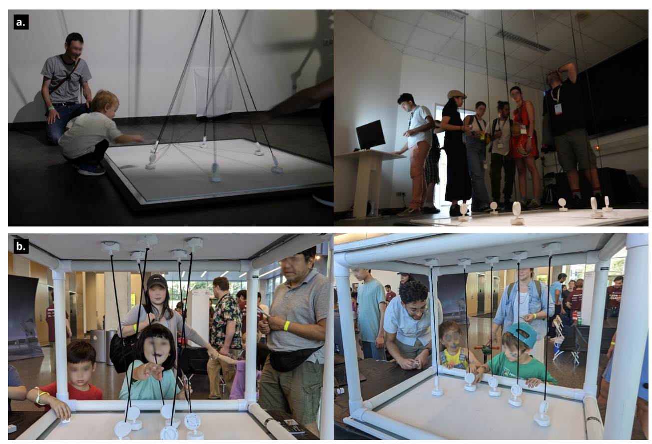

Figure 6: *Threading Space* Installations: a) Ars Electronica Festival, b) South Side Science Festival.

5 CONCLUSIONS

Threading Space creates a new medium of interaction between humans and technology: threads. Allowing viewers to physically interact with the artwork invites the audience to perceive threads in new ways – for example, by creating counterintuitive behavior for the threads or enabling multiple people to communicate using the sculpture. The hum of the moving robots, the shifting shadows cast on nearby walls, and the transforming three-dimensional patterns created by stretching threads all come together to form a cohesive kinetic sculpture. *Threading Space* uses symmetry and dissonance to create a unique, mesmerizing experience in which viewers can immerse themselves.

[1] https://ars.electronica.art/who-owns-the-truth/en/actuated-experience/
[2] https://southsidescience.event.uchicago.edu/

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